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Report: AQRB-84-004-L

Turbidity Studies at Resolute

by

Rao J. Polavarapu

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ABSTRACT

Atmospheric turbidity was measured at Resolute, a remote station located in Canadian Arctic to provide reference levels, ground truth for satellite and aircraft observations and to study trends. Turbidity data, surface air radiation and other air measurements were used for the period August 1983 to April 1984. At Resolute, the turbidity shows a slight increasing trend during the 11 month period with a value of 0.03.

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Date Completed: January 1984

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ABSTRACT

Atmospheric turbidity was evaluated at Resolute, a remote station located in Canadian Arctic to provide reference levels, ground truth for satellite and aircraft observations and to assess trends. Global solar, diffuse sky radiation and upper air measurements were used for the period March 1969 to April 1980. At Resolute, the turbidity shows a slight increasing trend having an 11-year mean value of 0.038.

The mean monthly turbidity variations from year to year are high in March and April, low in June and August and practically non-existent in September. The fairly constant turbidity in September implies that most of the atmospheric turbidity in that month is due mainly from stratospheric aerosol. This agrees with Mauna Loa observations that there exists a thin stratospheric aerosol layer of volcanic origin.

The seasonal variation in turbidity is very consistent from year to year with maximum occurring in late winter or early spring and minimum in late summer. This is in sharp contrast to reported turbidity variation in urban and non-urban areas where the monthly average turbidity shows a consistent annual pattern with low values in winter or spring and high values in summer. However, the present finding of late winter or early spring maximum and summer minimum is in agreement with aerosol measurements in the Canadian Arctic and at Barrow, Alaska.

Methodology is developed for evaluation of new aerosol factor which is analogous to turbidity coefficient. Using this method the aerosol factor was also evaluated at Resolute for the period March 1969 to April 1980.

INTRODUCTION

In the past few years there has been a growing concern that human activities might be affecting the global climate. The inadvertent injection of excessive amounts of particulate material could increase the background aerosol level and ultimately alter the earth energy balance. In order to establish the background aerosol levels and determine the extent to which they have been influenced by human activities, studies should be carried out at remote areas of the earth. The remote area studies may also provide information concerning global transport which is necessary for predictions of the ultimate distribution of particles injected into the atmosphere.

Resolute (74° 43'N, 94° 59'W) located in Canadian Arctic isolated from all major particle sources is considered to be a good remote station for assessing the background state of the atmosphere. At Resolute, atmospheric turbidity is evaluated for clear hourly periods from March 1969 to April 1980. Clear periods were selected on the basis of having transmissivity in excess of 0.7.

ANALYSIS

Initially, Linke's (1942) turbidity factor, a measure of the haze and water vapour content of the atmosphere, is estimated from global solar and diffuse sky radiation measurements as in Polavarapu (1978). This value is then corrected for water vapour absorption, resulting in an estimate of the aerosol content of the atmosphere, following the method of Yamamoto et al. (1968).

The solar radiation at normal incidence, I , is obtained from global solar radiation $K\downarrow$, diffuse radiation D and solar elevation h , as

$$I = (K\downarrow - D) / \sin h \quad (1)$$

The solar elevation is computed from solar declination δ , geographical latitude ϕ and hour angle H , by

$$\sin h' = \sin \phi \sin \delta + \cos \phi \cos \delta \cos H, \quad (2)$$

where $h' = h - \epsilon$ and ϵ is the refraction correction, which could be neglected for solar elevations greater than 10° . The hour angle at sunrise or sunset ($\sin h' = 0$) is computed from (2) as

$$\cos H = \tan \phi \tan \delta \quad (3)$$

for $|\tan \phi \tan \delta| < 1$. When $\tan \phi \tan \delta < -1$, H is taken as zero (polar night); when $\tan \phi \tan \delta > 1$, H is taken as 180° (24 hour daylight). At Resolute 24 hour daylight occurs in summer and no daylight in winter.

The declination in radians for Julian day, t , is given by

$$\delta = 0.4093 \sin [2\pi (t - 79.75)/365] \quad (4)$$

Atmospheric transmittance is defined as the ratio of downward irradiance in the earth's actual atmosphere to that received at the top of the atmosphere, i.e.,

$$T_Y = K \downarrow \gamma^2 / I_0 \sin h \quad (5)$$

where I_0 is the solar constant, taken as 1.367 mW m^{-2} . The ratio of actual to mean earth-sun separation, γ is given by

$$\gamma = 1 - 0.01673 \cos \tau \quad (6)$$

where τ in radians is given by

$$\tau = 2\pi t/365.$$

Linke's turbidity factor T is defined as

$$I = F^{-1} I_0 \exp [-T a_{R(m)}] \quad (7)$$

where I is the measured solar intensity of all wavelengths, $F = \gamma^2$ is the correction factor for mean solar distance, I_0 is the extra terrestrial solar

radiation, $\bar{a}_{R(m)}$ the mean value over all wavelengths of the Rayleigh extinction coefficient for unit air mass and m is the optical air mass.

Thus the Linke's turbidity factor is

$$\begin{aligned} T &= \frac{\ln I_0 - \ln I - \ln F}{\bar{a}_{R(m)} m} \\ &= P_{(m)} (\log I_0 - \log I - \log F), \end{aligned} \quad (8)$$

where

$$P_{(m)} = [\bar{a}_{R(m)} m \log e]^{-1}.$$

Values of $P_{(m)}$ are given in various sources such as CSAGI (1958) and Robinson (1966). The optical air mass m is approximately equal to $\csc h$ ($=\sec Z$, where Z is the zenith angle of the sun) and its values as given in CSAGI (1958) were used in the present study.

The integrated radiation values are given for each hour ending at local apparent time. For all periods in which the hourly radiation data have transmissivities in excess of 0.7, Linke's turbidity factor is determined and is considered as the mean value centered on the preceding hour. For a clear day in June 1969, the evaluation of Linke's turbidity factor is given in Table 1. In this evaluation, the solar elevation, optical air mass and $P_{(m)}$ are determined as instantaneous values centered on the hour.

ATMOSPHERIC TURBIDITY EVALUATION

If the observed solar intensity reduced to mean sun-earth distance is I , then we have:

$$I = \int_0^{\infty} [I_0(\lambda) \tau_R^m(\lambda) \tau_M^m(\lambda) \tau_{03}^m(\lambda)] \times [\bar{\tau}_{H_2O}(\lambda, mw, P, H_2O) \bar{\tau}_{CO_2}(\lambda, mu, P, CO_2)] d\lambda, \quad (9)$$

where

$$\text{solar constant, } I_0 \equiv \int_0^{\infty} I_0(\lambda) d\lambda$$

$\tau_R(\lambda)$ transmission in a Rayleigh atmosphere of unit air mass

$\tau_{03}(\lambda)$ transmission of ozone included in unit air mass

$\tau_M(\lambda)$ transmission of aerosols included in unit air mass

$\bar{\tau}_{H_2O}(\lambda, mw, P, H_2O)$ mean transmission in each of the near-infrared water vapor bands

$\bar{\tau}_{CO_2}(\lambda, mu, P, CO_2)$ mean transmission in each of the near-infrared carbon dioxide bands

w, u water vapor and carbon dioxide amounts, respectively in the vertical air column

m, P relative air mass and pressure parameters, respectively

λ wavelength

The intensity of solar radiation passing through a dust free (df) atmosphere is given as

$$I_{df} = \int_0^{\infty} [I_0(\lambda) \tau_R^m(\lambda) \tau_{03}^m(\lambda)] \times [\bar{\tau}_{H_2O}(\lambda, mw, P, H_2O)] \times [\bar{\tau}_{CO_2}(\lambda, mu, P, CO_2)] d\lambda \quad (10)$$

In the real atmosphere the transmission $\tau_M(\lambda)$ due to aerosols is dependent on m , w and β , the turbidity coefficient. The dependence of w , however, arises from an essential characteristic of aerosol particles, i.e., a

considerable number of aerosol particles, being hygroscopic in nature, change their size according to humidity in the atmosphere. Hence, the mean transmission due to aerosols is denoted by $\bar{\tau}_M(m, mw, m\beta)$ which can be obtained (9) and (10) as

$$\bar{\tau}_M(m, mw, m\beta) = I/I_{df}. \quad (11)$$

Yamamoto (1968) presented a chart for estimating the turbidity coefficient β from $\tau_M(m, mw, m\beta)$ for any given values of m and w and vice versa [i.e., $\tau_M(m, mw, m\beta)$ can also be estimated for any given values of β , m and w]. Substituting for the intensity of solar radiation I from (11) in (8), Linke's turbidity factor can also be evaluated as

$$T = P_{(m)}[\log I_0 - \log I_{df} - \log \bar{\tau}_M(m, mw, m\beta) - \log F] \quad (12)$$

From the above equation, Linke's turbidity factor for dust-free air, T_{df} [i.e., $\beta=0$; hence $\tau_M(m, mw, m\beta)=1$] is evaluated substituting the values of I_{df} from Yamamoto's (1968) chart. The values of T_{df} obtained as a function of optical air mass, m and precipitable water content, w are given in Table 2.

Polavarapu (1978) showed that Linke's turbidity factor, T is not constant even when the atmospheric turbidity remains constant. Hence, he introduced an aerosol factor defined as the difference in Linke's turbidity factors for an atmosphere containing water vapour and aerosols from that of dust-free air containing the same amount of water vapour. The values of aerosol factor, ΔT for a change of 0.025 in turbidity coefficient β are given in Table 3 reproduced from Polavarapu (1978). From this table it is obvious that ΔT is fairly constant in different atmospheric conditions for a given optical air mass, m . The aerosol factor varies with m being minimum at $m=1$ and increasing with increasing m . Hence, a new aerosol factor is introduced which is a function of atmospheric conditions only. The new aerosol factor is the product of aerosol factor and the correction factor given in Table 3. The correction factor is obtained by dividing the mean (0.403) of all values with the mean value of the given air mass.

DETERMINATION OF TURBIDITY COEFFICIENT FROM LINKE'S TURBIDITY FACTOR, T

Linke's turbidity factor for dust-free air, T_{df} , is given as a function of precipitable water and optical air mass in Table 2. From this table T_{df} is computed for given values of w and m . From the computed values of T for an atmosphere containing water vapour and dust and those for dust-free air, the aerosol factor, $\Delta T = T - T_{df}$ is determined. Knowing the value of $\Delta\beta/\Delta T$ from Table 4 which is reproduced from Polavarapu (1978), $\Delta\beta$ is obtained as a product of the two terms ΔT and $\Delta\beta/\Delta T$. $\Delta\beta$ is the change in turbidity coefficient from $\beta=0$ and hence it may be termed as β , the turbidity coefficient representing the aerosol content in the atmosphere.

EVALUATION OF TURBIDITY COEFFICIENT AND THE NEW AEROSOL FACTOR

Using the above methods the turbidity coefficient, β and the new aerosol factor were evaluated for all hourly radiation data from March 1969 through April 1980. In this evaluation the mean precipitable water content for the day obtained from 0600 LAT (00GMT) and 1800 LAT (1200 GMT) upper air measurements was used for all hours occurring in that day. The turbidity coefficient and the new aerosol factor evaluated for the same day (June 21, 1969) as given in Table 1 are shown in Table 5. Average monthly values are determined from the lowest possible 10 hourly values in a given month, but not exceeding three values for any day. If 10 values are not available a figure is given in parenthesis from which the means are computed. The range, mean and standard deviation of the turbidity coefficient is given in Table 6. The largest mean (.083) occurred in April 1977 and the smallest (.010) in August 1974. The standard deviation is lower from June through September and higher from March through May. The higher standard deviation is due mainly from an increase in turbidity during the spring months. Any data that has a standard deviation higher than 0.01 is questionable. In March, the data is of doubtful accuracy as the radiation measurements are possible only for one week with very short daytime and low intensity.

ANNUAL VARIATION

Annual means of atmospheric turbidity coefficient and aerosol factor are computed from the monthly means for 1969 to 1979 and presented in Fig. 1. Monthly means of March and September (see Table 6) are not included in the annual means because of missing data in several years. The turbidity

coefficient reached a minimum value of 0.025 in 1971 and a secondary minimum (0.037) in 1976. The 1971 minimum is in agreement with studies of Pueschel et al. (1972), who carried through a very careful analysis of radiation data from Mauna Loa. They concluded that the Bali volcanic eruption of 1963 produced an observable increase in global turbidity, which had virtually disappeared by 1971. The secondary minimum is also in agreement with Mauna Loa turbidity data, Hanel (1979), that has decreased by about 15% from 1975 value. The turbidity is fairly constant at Resolute from 1973 to 1975, reaching a maximum in 1975, while at Mauna Loa it is constant from 1972 to 1975. The reasons for the lower value at Resolute in 1972 has yet to be investigated. It may be due to the fact that the annual values at Resolute are obtained from the monthly estimates of April through September while at Mauna Loa they were obtained from all months. The variation in annual mean at Resolute is due mainly to variations in turbidity in spring when it is at the annual maximum. At Resolute the turbidity shows a slight increasing trend with time. The 11 year mean value of 0.038 is in good agreement with the earlier analysis of Polavarapu (1978).

The mean monthly turbidity variation from year to year in a given month are given in Figs. 2(a), (b), (c) and (d). The year to year variations are high in March and April and low in June and August and practically non-existent in September. The large variations in July are surprising even though the 11 year mean is the same as that of June. The variations in July from year to year may be due to the variations in wet processes occurring in clouds and precipitation as they are the most effective mechanisms of aerosol removal. The fairly constant turbidity in September from year to year may be due to the larger contribution from stratospheric aerosol and smaller contribution from tropospheric aerosol. It is known that the stratospheric aerosol layer has a longer time constant while the tropospheric layer has a very short time constant. The vertical turbidity is considered as the sum of tropospheric variations super-imposed on the stratospheric background. Hence in September the contribution from stratospheric layer may be 0.01 (tropospheric 0.007). If so, this agrees with Mauna Loa observations of Shaw (1980), that there exists a thin stratospheric layer of intervolcanic value of turbidity (~ 0.01).

SEASONAL VARIATION

The mean seasonal variation of turbidity obtained from monthly means of 1969 to 1980 is presented in Fig. 3. The maximum occurs in March or April and minimum in August or September. This is in sharp contrast to turbidity measurements at urban and non-urban areas reported by Peterson et al. (1981), Polavarapu (1978), Peterson and Flowers (1976), Flowers et al. (1969). Their measurements of monthly average turbidity show a consistent annual pattern with low values in winter and spring and high values in summer. However, the present finding of late winter or early spring maximum and summer minimum is in agreement with aerosol measurements in the Canadian Arctic by Barrie et al. (1981) and at Barrow, Alaska (Rahn and McCaffrey, 1980).

The seasonal variation in turbidity for all years from 1969 to 1980 is given in Figs. 4(a), (b) and (c). The variation is very consistent from year to year with maximum occurring in late winter or early spring and minimum in late summer. The seasonal variation is large in 1974, 1975 and 1977 and small in 1970 and 1971. This means that at high annual turbidities the seasonal variation is large and at low annual values the seasonal variation is small.

SUMMARY

At Resolute atmospheric turbidity is evaluated from global solar and sky radiation measurements with the use of upper air data. Initially, Linke's turbidity factor is estimated from hourly radiation data when the atmospheric transmittance is greater than 0.7. From the Linke's turbidity factor and precipitable water content, the atmospheric turbidity coefficient is computed following Polavarapu (1978). Also, a new aerosol factor (developed in this paper) which is analogous to turbidity coefficient is also evaluated. Average monthly values are determined from the lowest possible 10 values in a given month. From the monthly means annual variation in turbidity is presented. The annual variation is in agreement with Mauna Loa turbidity data. At Resolute the turbidity shows a slight increasing trend with time. The 11 year mean value of 0.038 is in good agreement with the earlier analysis of Polavarapu (1978).

The mean monthly turbidity variation from year to year for each month is also presented. The year to year variations are high in March and April and low in June and August and practically non-existent in September. The fairly constant turbidity in September implies that most of the atmospheric turbidity in that month is due mainly from stratospheric aerosol. This agrees with Mauna Loa observations of Shaw (1979) that there exists a thin stratospheric layer of intervolcanic value of turbidity (~ 0.01).

The seasonal variation in turbidity in each year and also the mean for all years is presented. The variation is very consistent from year to year with maximum occurring in late winter or early spring and minimum in late summer. This is in sharp contrast to reported turbidity variation in urban and non-urban areas where the monthly average turbidity shows a consistent annual pattern with low values in winter and spring and high values in summer. However, the present finding of late winter or early spring maximum and summer minimum is in agreement with aerosol measurements in the Canadian Arctic and at Barrow, Alaska. More research is needed to uncover the reason for the spring maximum at Resolute and other remote stations.

Atmospheric turbidity studies at remote locations far from anthropogenic pollution sources such as at Resolute are required, apart from their importance in climate studies, to provide reference levels, ground truth for satellite and aircraft observations and to provide trend data.

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TABLE 1 Linke's turbidity factor evaluation at Resolute (74°43'N, 94°59'W) on a clear day, 21 June 1969.

Local Apparent Time (hr)	Global Solar Radiation $K \downarrow$ (MJ m ⁻²)	Diffuse Radiation D (MJ m ⁻²)	Atmospheric Transmittance	Solar Elevation h (deg)	Optical Air Mass (m)	P (m)	Solar Intensity I (MJ m ⁻²)	Linke's Turbidity (T)
0500	0.996	0.247	0.718	16.927	3.435	8.448	2.573	2.259
0600	1.306	0.301	0.779	20.617	2.840	9.746	2.854	2.167
0700	1.520	0.327	0.769	24.535	2.408	11.081	2.873	2.432
0800	1.762	0.356	0.777	28.439	2.100	12.361	2.952	2.566
0900	1.988	0.377	0.786	32.065	1.884	13.498	3.035	2.641
1000	2.185	0.389	0.797	35.136	1.738	14.437	3.121	2.650
1100	2.327	0.402	0.805	37.379	1.647	15.122	3.171	2.671
1200	2.407	0.419	0.811	38.567	1.604	15.468	3.189	2.694
1300	2.394	0.427	0.806	38.567	1.604	15.468	3.155	2.765
1400	2.332	0.427	0.807	37.379	1.647	15.122	3.138	2.739
1500	2.185	0.414	0.797	35.137	1.738	14.437	3.077	2.738
1600	0.980	0.398	0.783	32.066	1.884	13.498	2.980	2.748
1700	1.750	0.368	0.772	28.439	2.100	12.361	2.902	2.659
1800	1.507	0.335	0.762	24.536	2.408	11.081	2.822	2.517
1900	1.239	0.297	0.739	20.618	2.840	9.746	2.675	2.441
2000	1.000	0.264	0.721	16.928	3.435	8.448	2.528	2.324

TABLE 2 Linke's turbidity factor for dust-free air, given as a function of optical air mass, m and precipitable water content, w .

Precipitable Water Content w (cm)	Optical Air Mass, m				
	1	2	3	4	5
0.01	1.30384	1.2293	1.1818	1.1604	1.486
0.05	1.4778	1.3726	1.3081	1.2850	1.2681
0.1	1.6263	1.4642	1.3941	1.3545	1.3359
0.5	2.0416	1.7454	1.6222	1.5825	1.5607
1.0	2.2736	1.9027	1.7718	1.7116	1.688
2.0	2.5660	2.0846	1.9336	1.8535	1.812
5.0	2.6982	2.2291	2.0336	1.9215	1.8721

TABLE 3 Aerosol Factor ΔT given as a function of optical air mass, m and atmospheric turbidity, β for $\Delta\beta=0.025$. (Correction factor for the new aerosol factor is also given).

Atmospheric Turbidity Coefficient β	Optical Air Mass, m				
	1	2	3	4	5
$w = 0.5 \text{ cm}$					
0.0 -0.025	0.350	0.390	0.42	0.43	0.44
0.025-0.050	0.360	0.390	0.41	0.42	0.43
$w = 1.0 \text{ cm}$					
0.0 -0.025	0.360	0.390	0.41	0.43	0.44
0.025-0.050	0.360	0.390	0.41	0.42	0.43
0.050-0.100	0.355	0.380	0.405	0.42	0.44
$w = 2.0 \text{ cm}$					
0.0 -0.05	0.365	0.390	0.405	0.425	0.45
0.05 -0.10	0.360	0.390	0.40	0.420	0.44
0.10 -0.20	0.360	0.380	0.39	-	-
Mean	0.359	0.387	0.406	0.424	0.439
Correction Factor	1.123	1.041	0.993	0.950	0.918

TABLE 4 Variation of $\Delta\beta/\Delta T$ with optical air mass.

β	Optical Air Mass, m				
	1	2	3	4	5
w = 0.5 cm					
0.0-0.025	0.0714	0.0641	0.0595	0.0581	0.0568
0.0-0.050	0.0704	0.0641	0.0603	0.0588	0.0575
w = 1.0 cm					
0.0-0.025	0.0694	0.0641	0.0610	0.0581	0.0568
0.0-0.050	0.0694	0.0641	0.0610	0.0588	0.0575
0.0-0.100	0.0699	0.0649	0.0613	0.0592	0.0571
w = 2.0 cm					
0.0-0.05	0.0685	0.0641	0.0617	0.0588	0.0556
0.0-0.10	0.690	0.0641	0.0621	0.0592	0.0562
0.0-0.20	0.0692	0.0651	0.0610	-	-
Mean	0.0696	0.0643	0.0610	0.0587	0.0568

TABLE 5 Evaluation of turbidity coefficient and new aerosol factor at Resolute on 21 June 1969.

Local Apparent Time (hr)	Atmospheric Transmittance	Optical Air Mass (m)	Linke's Turbidity Factor T	Precipitable Water Content w (cm)	Linke's Turbidity Factor for dust- Free Air, T_{df}	$(T-T_{df})$ $=\Delta T$	$\frac{\Delta \beta}{\Delta T}$	Turbidity Coefficient β	Aerosol Correc- tion Factor	New Aerosol Factor
0500	0.718	3.435	2.259	0.686	1.657	0.602	0.060	0.036	0.974	0.586
0600	0.779	2.840	2.167	0.686	1.698	0.469	0.062	0.029	1.001	0.469
0700	0.769	2.408	2.432	0.686	1.752	0.680	0.063	0.043	1.021	0.694
0800	0.777	2.100	2.566	0.686	1.791	0.775	0.064	0.050	1.036	0.803
0900	0.786	1.884	2.641	0.686	1.841	0.800	0.065	0.052	1.051	0.840
1000	0.797	1.738	2.650	0.686	1.889	0.761	0.066	0.050	1.062	0.809
1100	0.805	1.647	2.671	0.686	1.918	0.753	0.066	0.050	1.070	0.805
1200	0.811	1.604	2.694	0.686	1.932	0.762	0.066	0.051	1.073	0.818
1300	0.806	1.604	2.765	0.686	1.932	0.833	0.066	0.055	1.073	0.894
1400	0.807	1.647	2.739	0.686	1.918	0.821	0.066	0.054	1.070	0.878
1500	0.797	1.738	2.738	0.686	1.889	0.849	0.066	0.056	1.062	0.902
1600	0.783	1.884	2.748	0.686	1.841	0.907	0.065	0.059	1.051	0.952
1700	0.772	2.100	2.659	0.686	1.791	0.868	0.064	0.056	1.036	0.899
1800	0.762	2.408	2.517	0.686	1.752	0.765	0.063	0.048	1.021	0.781
1900	0.739	2.840	2.441	0.686	1.698	0.743	0.062	0.046	1.001	0.744
2000	0.721	3.435	2.324	0.686	1.657	0.667	0.060	0.040	0.974	0.650

YEAR	MARCH			APRIL			MAY			JUNE			JULY			AUGUST			SEPTEMBER		
	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.	Range	Mean	Std. Dev.
1969	.046-.059	.055	.0037	.032-.048	.041	.0045	.052-.063	.057	.0029	.026-.038	.034	.0038	.037-.062	.050	.0083	.014-.022	.017	.0027	.004-.021	.012	.0055
1970	.032-.047	.038	.0049	.033-.047	.041	.0049	.033-.038	.035	.0016	.036-.043	.039	.0021	.014-.019	.018	.0014	.003-.024	.012	.0079	.005-.024	.012	.0056
1971	-	-	-	.030-.042	.036	.0043	.028-.037	.033	.0035	.020-.030	.025	.0035	.001-.015	.009	.0042	.005-.038	.024	.011	.012-.023	.016	.0040
1972	.024-.027	.026	.0014	.025-.059	.049	.0091	.025-.056	.044	.0095	.019-.044	.033	.0089	.007-.026	.017	.0057	.001-.016	.0095	.0051	.005-.024	.013	.0060
1973	.049-.054	.052	.0021	.046-.070	.057	.0085	.046-.053	.050	.0022	.030-.037	.034	.0024	.037-.043	.040	.0020	.025-.029	.027	.0016	-	-	-
1974	.073-.098	.087	.0091	.064-.078	.072	.0047	.052-.074	.070	.0063	.016-.027	.024	.0032	.023-.037	.031	.0042	.007-.015	.010	.0026	-	-	-
1975	-	-	-	.074-.088	.083	.0044	.037-.058	.047	.0066	.017-.027	.024	.0036	.023-.057	.037	.0097	.030-.038	.035	.0024	-	-	-
1976	-	-	-	.019-.054	.042	.0124	.036-.075	.061	.0111	.022-.030	.026	.0028	.013-.022	.019	.0029	.013-.030	.022	.0058	.010-.022	.015	.0035
1977	-	-	-	.062-.085	.074	.0083	.042-.059	.053	.0046	.018-.025	.023	.0022	.015-.024	.023	.0026	.009-.016	.014	.0023	-	-	-
1978	.032-.085	.065	.0139	.019-.064	.050	.0128	.009-.062	.045	.0170	.027-.047	.040	.0061	-	-	-	.019-.019	.019	-	-	-	-
1979	.061-.083	.072	.0071	.035-.059	.051	.0080	-	-	-	-	-	-	.036-.090	.057	.0162	.013-.033	.024	.0071	.007-.012	.009	.0025
1980	.050-.084	.067	.0170	.051-.064	.057	.0039	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 6 Includes the range and standard deviation of turbidity coefficient β in the monthly means.
A number is given in parenthesis if the values used in obtaining the mean are less than 10.

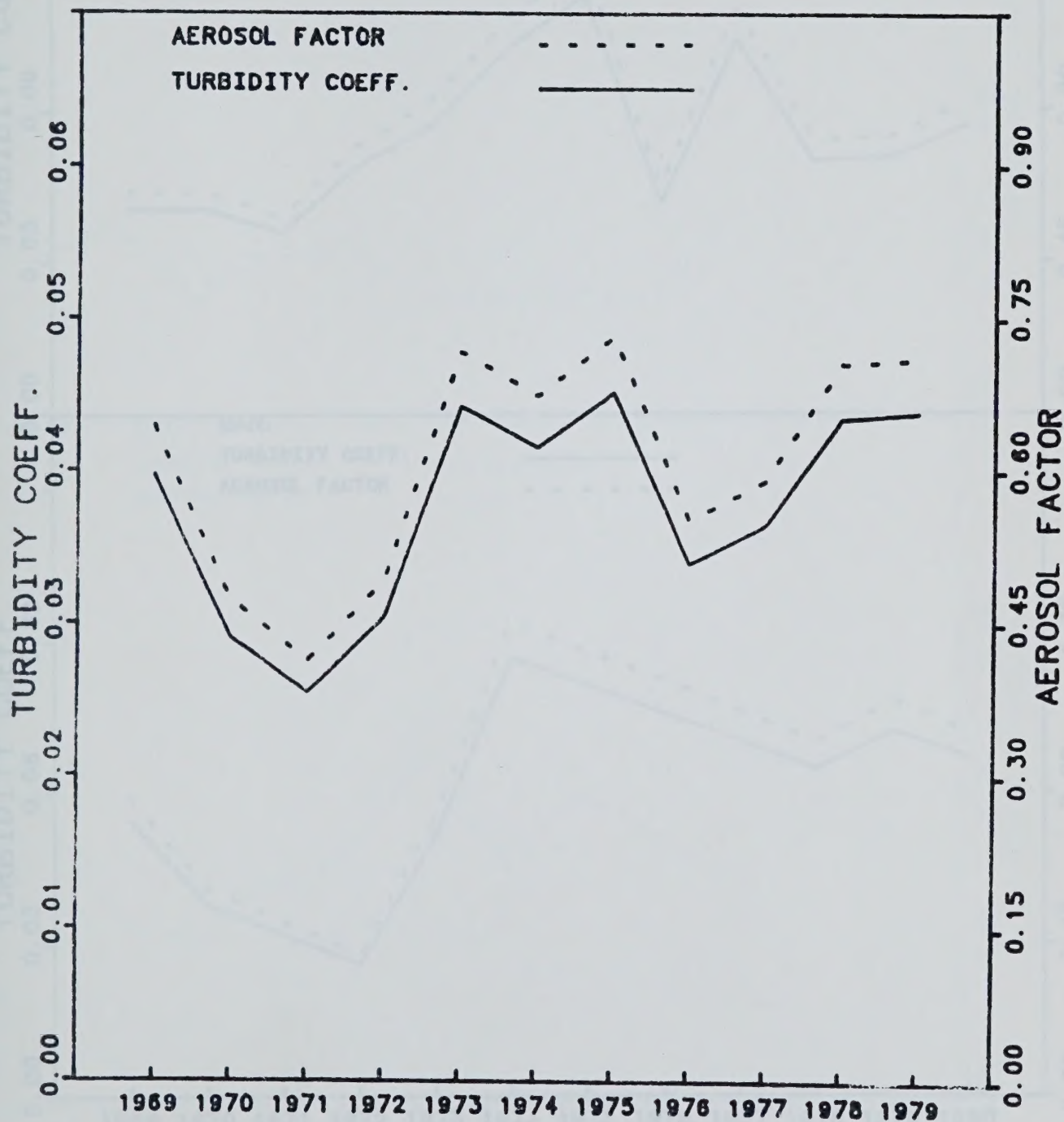


Figure 1 Annual mean variation in atmospheric turbidity coefficient and aerosol factor at Resolute.

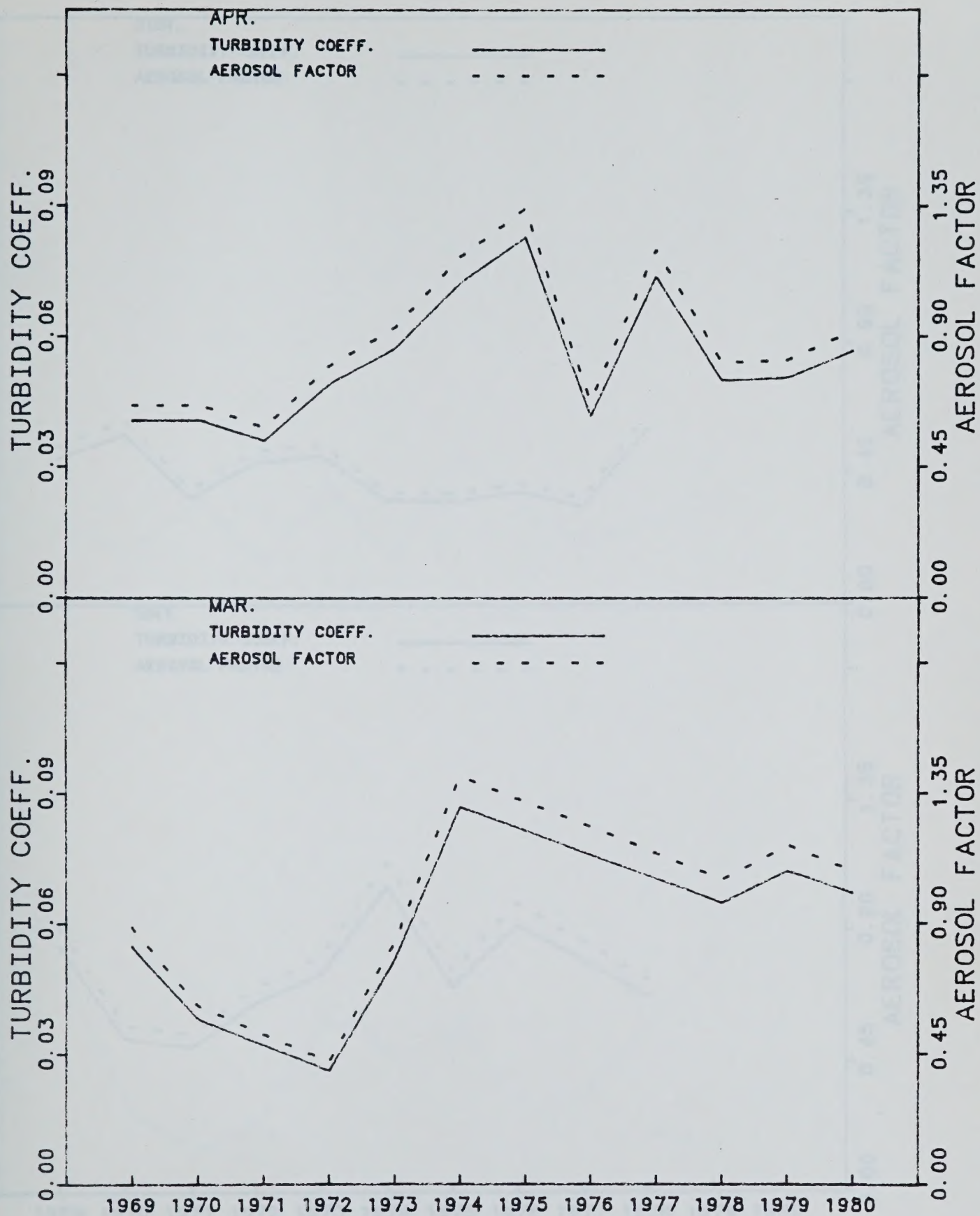


Figure 2a Monthly mean turbidity variation from year to year in March and April.

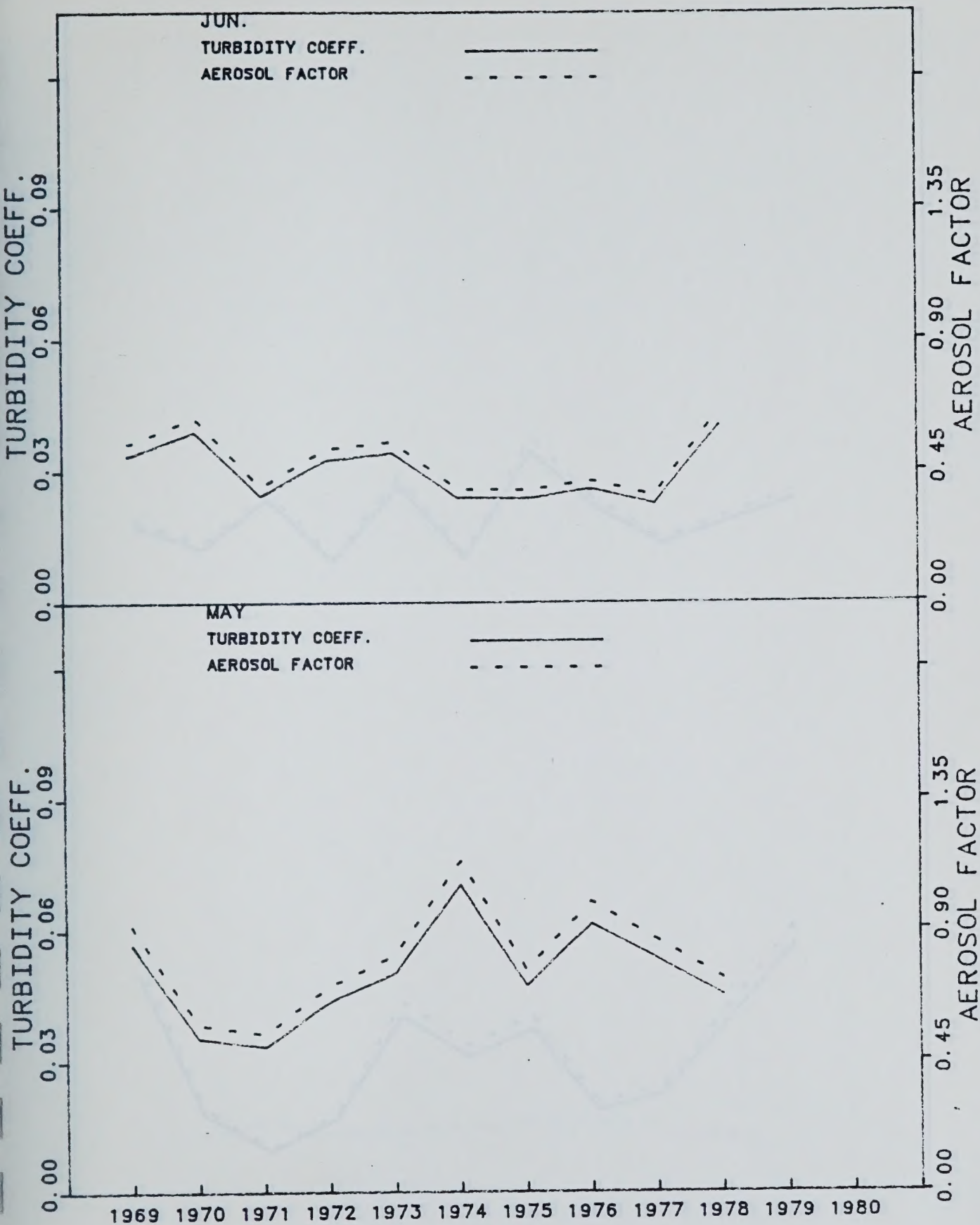


Figure 2b As in Figure 2a except for May and June.

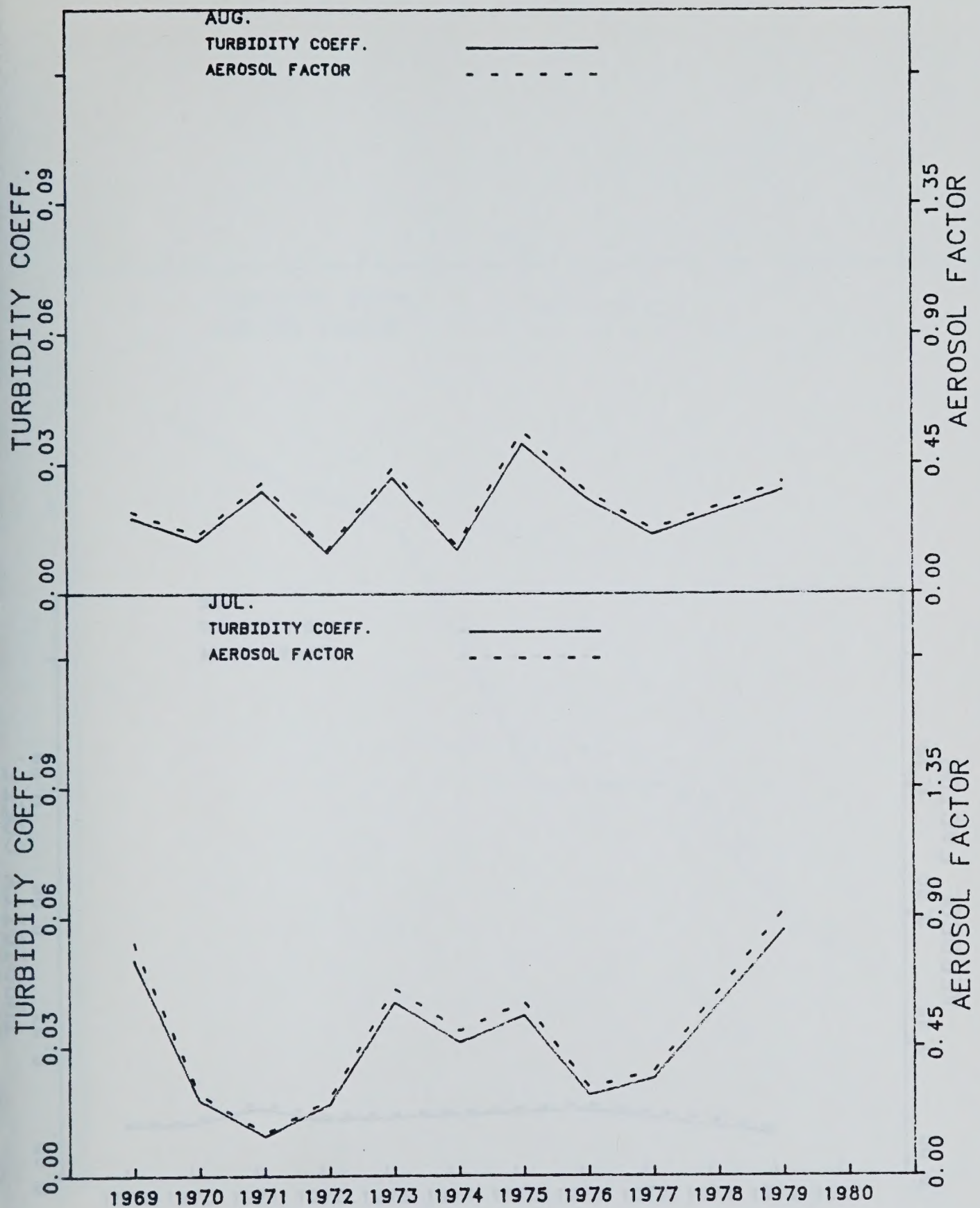


Figure 2c As in Figure 2a except for July and August.

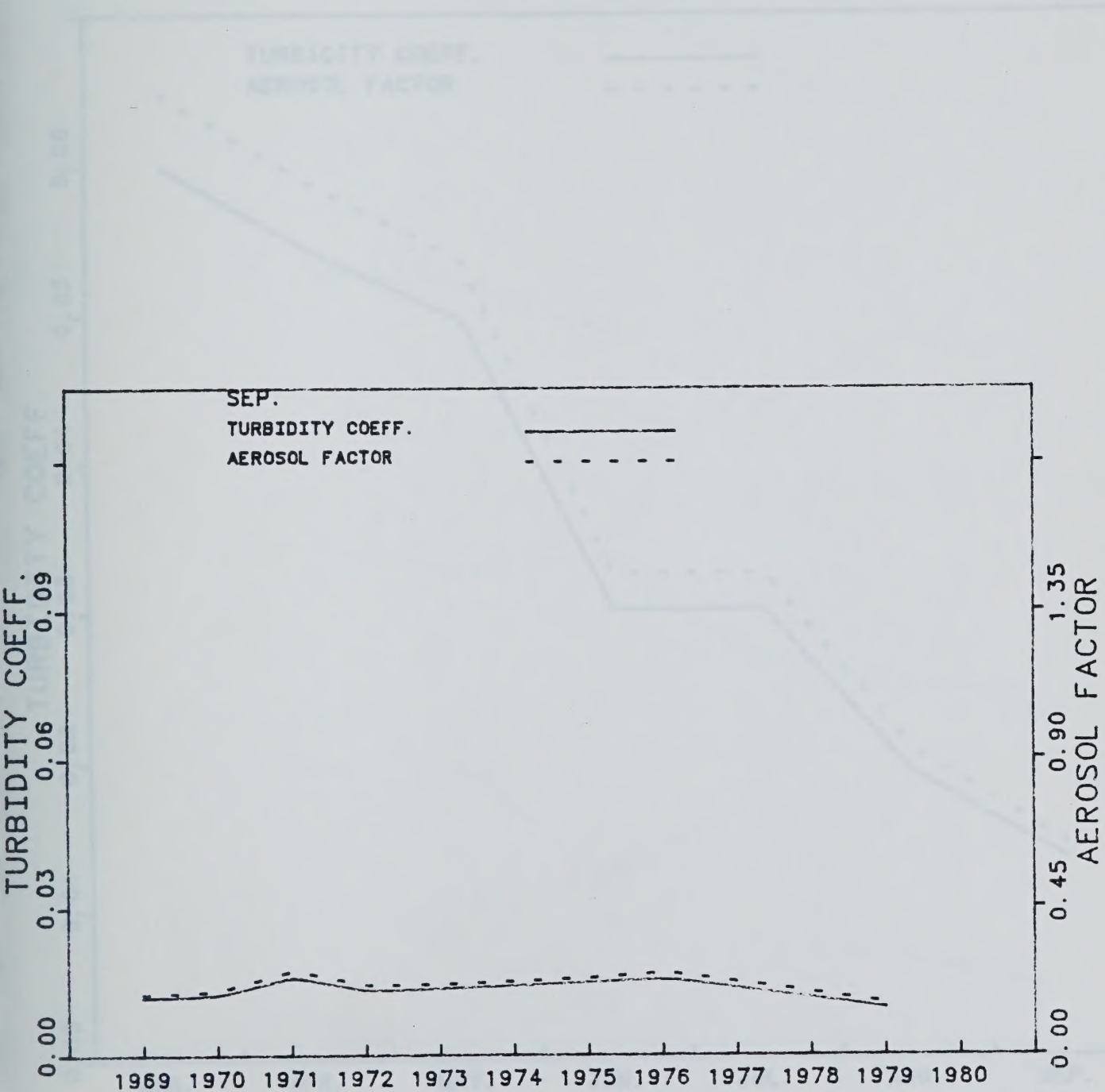


Figure 2d As in Figure 2a except for September.

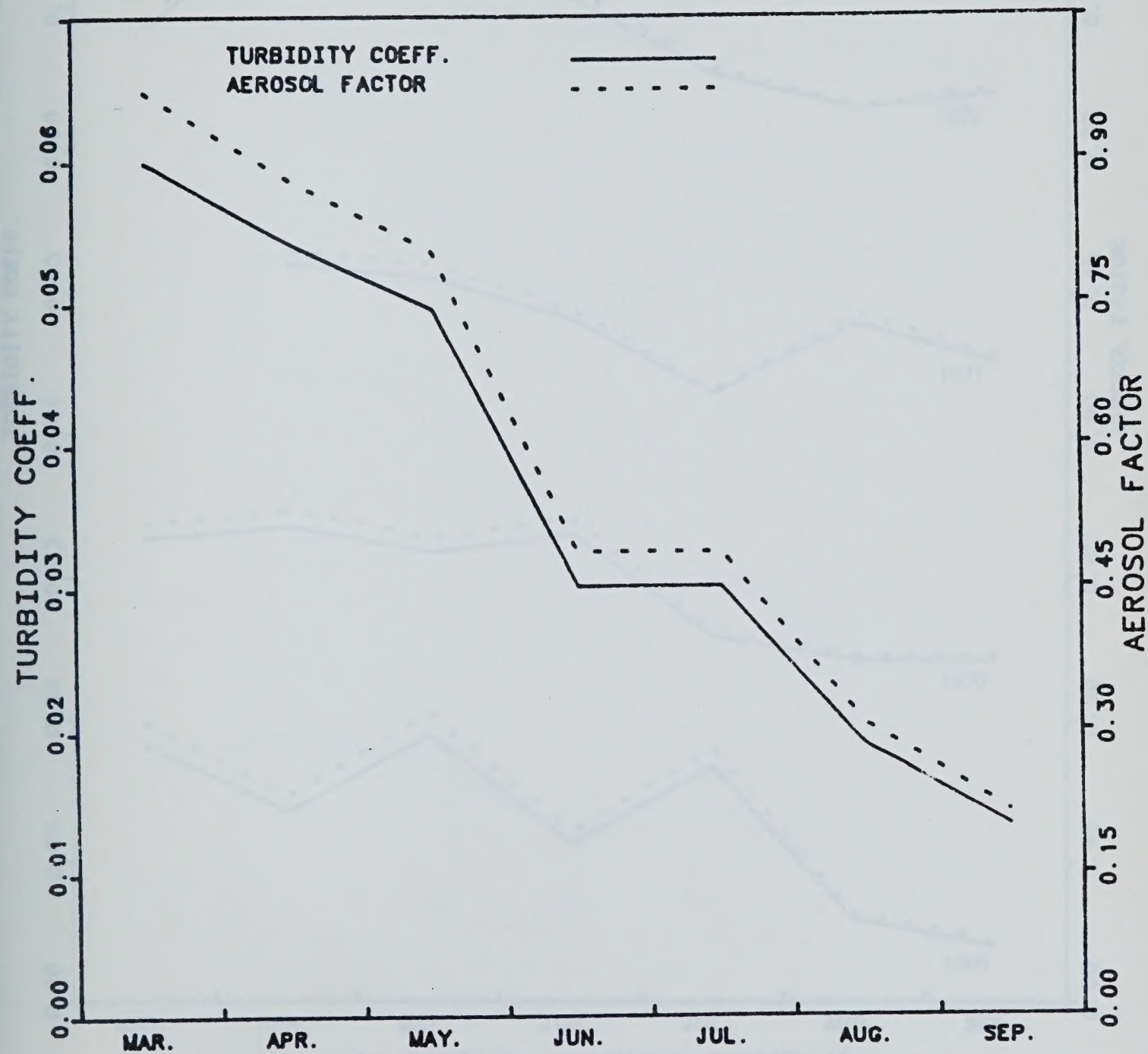


Figure 3 Monthly mean turbidity averaged for the period March 1969 to April 1980.

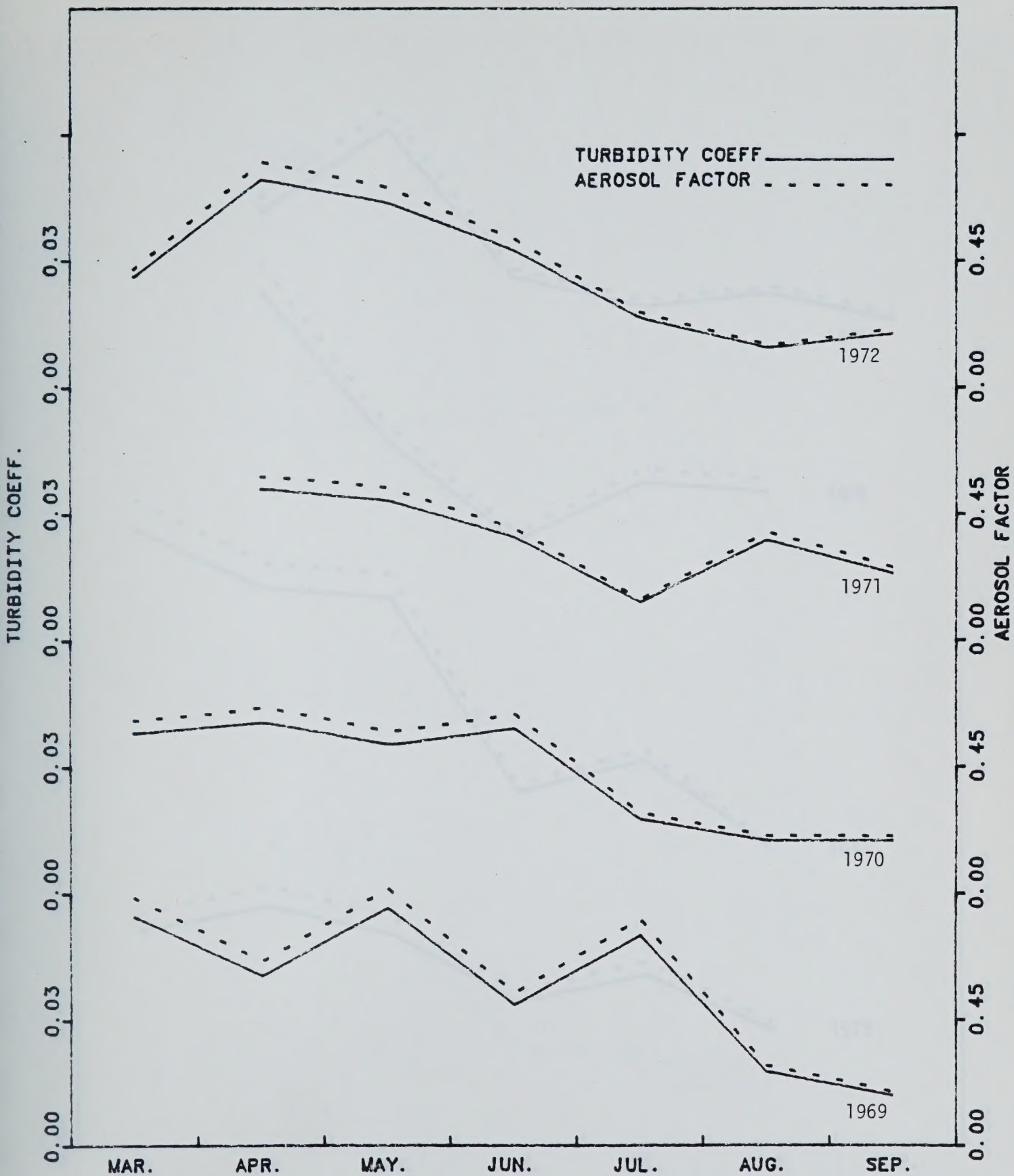


Figure 4a Monthly mean variation in turbidity in 1969, 1970, 1971 and 1972.

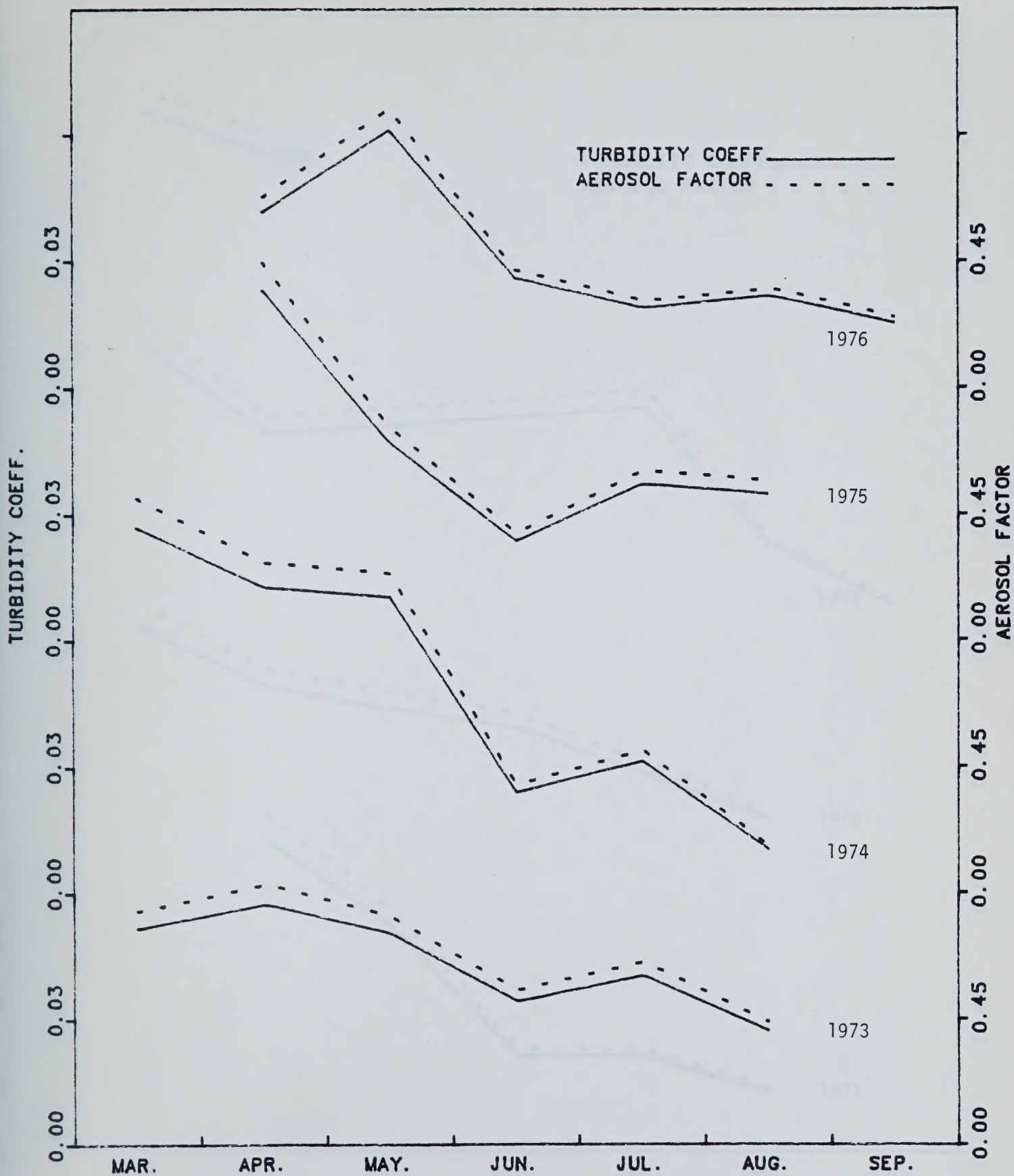


Figure 4b As in Figure 4a except for 1973, 1974, 1975 and 1976.

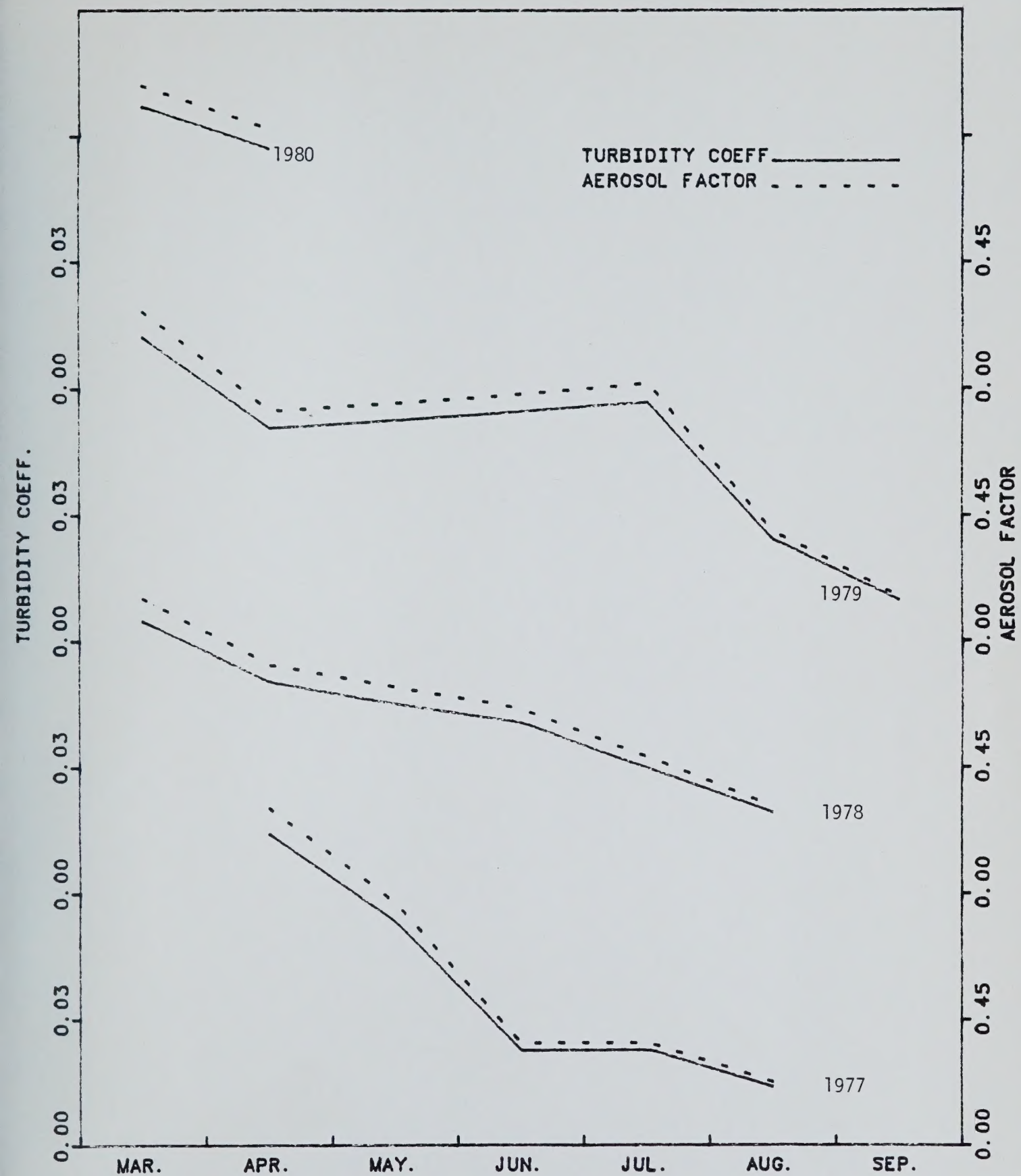


Figure 4c As in Figure 4a except for 1977, 1978, 1979 and 1980.

*Three Dark Figures
Making the Weather
In Folk, in Myth, in Legend,
A threefold test.
Shiva, Vishnu, Brahmin.
Father, Son, Holy Ghost.
Body, Mind, Spirit.
Triune, Triumvirate, Tribunal.
One is Isolate
Two is divisive
Three is Peace.
Three is Torment.
Three is Potent.
Power, Power, Power.
Air, Fire, Water.
Three Dark Figures,
Making the Weather.*

Ron Baird, Sculptor